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Energy Savings In Air Heating Stove Of Tea Plant Using Repetitive Control Strategy

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ABSTRACT
Many of the production costs for producing tea are attributable to the process of drying the tea. Automation of this process can assist companies to reduce these production costs by making crucial information at right time. This paper presents an application of new control strategy to the design of an automatic tea drying control system. This control system will ensure that the multiple drying parameters such as temperature, dryer-exit tea moisture content, and fuel consumption are maintained at optimal states during the course of the drying process. The additional aim of this control strategy system is to balance the cost of production by means of reducing the wood feeding and the quality of the final product. Results show that proposed control strategy gives finer performance in all aspects.

Key Word: NMRCS, repetitive control, Conventional PI, Tea plant

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I. INTRODUCTION

There is no alternative to drying tea, which is the most energy-intensive and most expensive process in the manufacture of tea, as stated by Saeed[1]. For Indian tea companies that experience high energy costs, there is a need for innovation in this control area that balances the cost of production and the quality of the final product. In order to reach this balance, the factory needs to be constantly monitored by decision-makers in order to obtain the correct and appropriate information on the factory's processes. Developments in automation and the development of control strategies have enabled inventions of new and better methods to provide information, monitor, and keep processes under control in a factory.

This paper presents the design of an online automatic tea drying control system for a tea company. The design aims to eliminate errors associated with the dependency on people who currently regulate the dryer environment in tea production. Currently, the drier operator controls the dryer by monitoring the drier exit tea, feeling and smelling the tea in order to determine the moisture content of this tea. The intention of this paper is therefore to present a design that will continuously monitor and control the temperature, humidity, and pressure inside a drier. In addition, the fuel feed system can be automated.

II. TEA DRYING CONTROL

The main objectives of tea drying are to preserve the tea leaves and produce a stable, quality product by arresting enzyme activity, halting oxidation, and removing moisture from a leaf's particles. According to Rudramoorthy et al. [2], 100 kg of fresh leaves produces, on average, 22.5 kg of dried tea that contains only 3-4 per cent of residual moisture. The 77.5 kgs difference between the fresh leaves and the dried tea represents the moisture that was evaporated during the process of withering and drying: approximately 20-25 kg is evaporated during the withering process, and around 20-50 kg is evaporated during the drying process. Here the Drying time is approximately 20 minutes absorbed.

Since the labour costs of tea production in India are low, automation, monitoring, and process control were not really an issue for a long time. Companies are, however, becoming increasingly concerned about the operational and energy costs in tea processing because they are becoming highly energy-intensive. This is the case in Sri Lanka, for example, where the tea industry is the largest consumer of firewood and electricity, and almost the second largest consumer of oil [3]. There is therefore a need to develop more energy-efficient technologies. A great deal of energy can be saved in tea production if the tea drying process is controlled. According to Bagheri et al. [4], a ten per cent increase in profit can be achieved by increasing energy efficiency by only one per cent.

The issues that need to be taken into consideration when drying tea include monitoring and detecting the inlet and outlet air temperature, the drying time, the air volume, and the feed tea, which can differ in its moisture contents and grade. In most factories, process control in tea drying is carried out manually. Typical dryer capacity fluctuates from approximately 100 kg/hr to 300 kg/hr, and the average fuel consumption is around 45 kg/hr. Absence of an energy use control system leads to energy waste and to lower throughputs [5]. Even though producers are aware of the importance of process control and how it leads to better quality, they are reluctant to invest in high technology equipment.

III. MATHEMATICAL MODEL OF THE TEA PLANT

In real time, the system parameters of the tea plant are identified by adapting black box modeling technique. Initially, temperature of the furnace is sustained by feeding 5 tons of wood, the speed of the induced fan is maintained at 60% and there by supervise the dryer unit at 120°C. A sudden disturbance (-10% of speed) is given by adjusting the speed of the induced fan thereby reached a new steady state temperature. Using the open loop method, for a given change in the input variable; the output response for the system is recorded. From the recorded data, the FOPTD model is identified and noted. The same procedure is repeated and the FOPTD model is identified for the dryer temperature at 88°C. From the recorded data, the model parameters such as process gain (Kp) time constant (τp) and delay (td) are computed and tabulated in Table 1.

***Table 1*: Identification of Tea process parameters**

Operating Point (%)	K_p	τ_p	t_d
66 (%)	-1.11	398	52
48 (%)	-0.833	420	60

From the table, the average values are calculated and summarized below

$$G(s) = \frac{-0.975e^{-56s}}{409s+1}$$

Based on the average case model parameters, P mode and PI mode controller settings (K_c = -7.56, K_c = -5.6 and Ki = -0.03) are computed by considering Z-N [6] open loop tuning rule.

IV. REPETITIVE CONTROL

The basic RC is a model free approach to achieve a better system performance of systems over a finite time interval. It is proposed by B.A.Francis [7] for use in the control of proton synchrotron magnetic supply. It is later developed to be used in applications that required repetitive operations such as pick and place operations in robotics. The main idea associated with the use of the RC is to enhance the system performance by using the information from the previous cycle in the next cycle over a period of time until the performance achieved is considered to be satisfactory. Figure 1 shows the usual RC configuration.

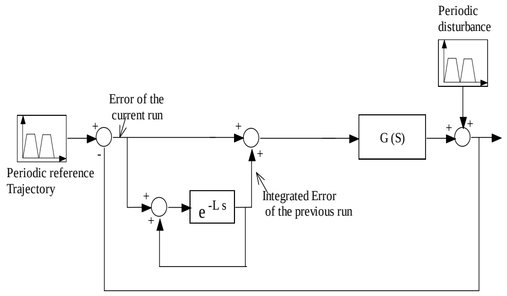

Fig. 1. Basic Repetitive Control Strategy

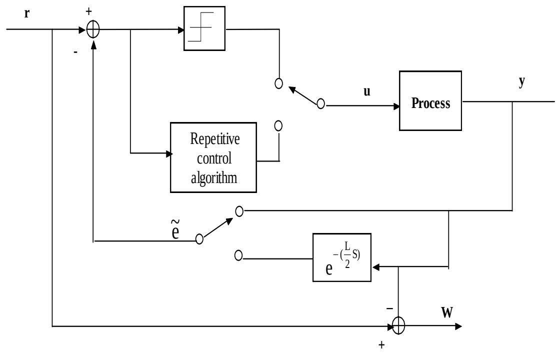

Fig. 2. Repetitive control algorithm with relay feedback.

An RC approach is used to design PI controllers [8].While this configuration works well for robotic and servo control applications with a moderately small time delay, it will fail in the area of process control applications and requirements due to the typical presence of time delay and large phase lag. In order for the RC scheme to be applicable to processes with long dead time, the basic form is modified by adding a time delay block to the feedback path as shown in Figure 2.

The relay feedback configuration as shown in Figure 2 is first applied to the process to obtain the repetitive excitation signal. Then the process is switched to RC mode. Since the ultimate frequency, y and u is out of phase by π, the additional delay block $e^{(-L/2)s}$ (where L is period of reference input) is introduced to align the phase of ẽ and u to remain in phase so that the RC remains valid even in the occurrence of large delay. Once the suitable tracking performance is accomplished through the Repetitive Control Strategies, the signals W (error signal) and U (control signal) are attained and exercised to find the optimum PI controller parameters by using recursive least square algorithm (RLS). Here P-type update law is adopted for the RC.

4.1 New Modified Repetitive Control (NMRC)

The modeling of tea plant is uncertain for high frequency signals. Due to uncertainty, noise will have a great influence on the response, which affects the stability of the process. To overcome this problem, a low-pass filter (Q) and learning filter (L_f) is added to the existing RC control loop and to ensure system stability. The Key factors such as Learning filter (L_f) and Robustness filter (Q) in the learning control strategy are identified using Zero Phase Error Tracking Control (ZPETC) technique and frequency method respectively. To improve the stability of RCS a New Modified Repetitive Control Strategy (NMRCS) is implemented and as shown in Figure 3. Where V is the stable rational factor ($0 < V < 1$).

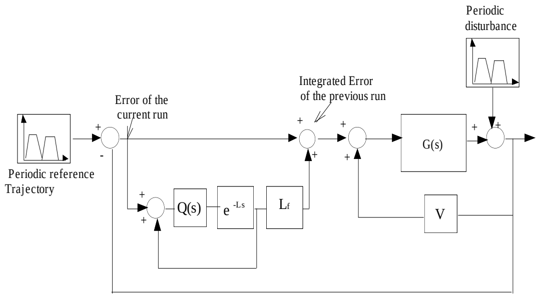

Fig 3. New Modified Repetitive Control Strategy

V. RESULTS AND DISCUSSION

To analyze the effectiveness of the NMRCS based PI tuning method, design parameters such as learning filter L_f , robustness filter Q and rational factor V are designed initially by considering the Tea plant.

5.1 Design procedure and guidelines

Learning filter design

The Learning filter (L_f) is nothing but the inverse of process-sensitivity (T) = $\frac{GC}{1+GC}$ i.e $L_f = KT^{-1}$. Due to the unstability and non-proper characterisitics of inverse complementary sensitivity, L_f can not be act as a filter. This problem is overcome by adapting Zero Phase Error Tracking Controller (ZPETC) algorithm [9].The evaluation of ZPETC method is done by comparing the bode plot of the original inverse complementary sensitivity and the approximated inverse complementary sensitivity as shown in Figure 4. It seems that the magnitude and phase plots of both the cases are same. In this the phase plot, the phase caused by the delay has been taken into account. The identified Learning filter (L_f) is given by

$$L_f(s) = \frac{2.958e^9 s^3 + 2.124e^8 s^2 + 6.309e^7 s + + 2.117e^6}{s^3 + 60s^2 + 1200s + 8000}$$

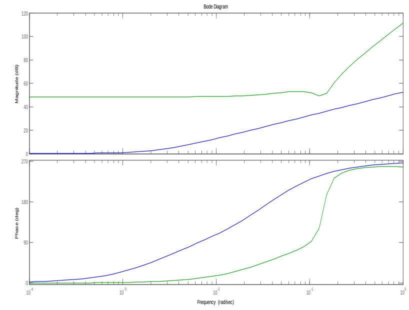

Fig.4. Bode plot of Inverse Complementary sensitivity

Low pass filter design

A first order continuous time low pass filter is considered here. i.e $Q(s) = \frac{\omega_c}{s+\omega_c}$, where ω_c is the cut-off frequency in rad /sec. The cut-off frequency is obtained from the Bode plot of the tea plant system (refer Figure. 5). In this study, it is found to be 0.0295.

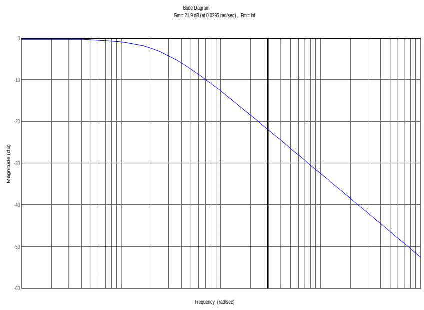

Fig.5. Magnitude plot of the Tea plant system

Rational factor design

Using an optimization technique the value of stable rational factor (V) has been chosen corresponding to minimum tracking error and to enhance the stability of NMRCS. The identified value of V for tea plant is 0.8. In addition to that, the learning gain (K) and it is chosen as 0.3.

Simulation Results

The relay feedback arrangement, as shown in Figure.2, is first applied to the process to get the repetitive excitation signal for the NMRCS as shown in Figure 6. Then the process is switched to NMRCS set up with the repetitive excitation signal.

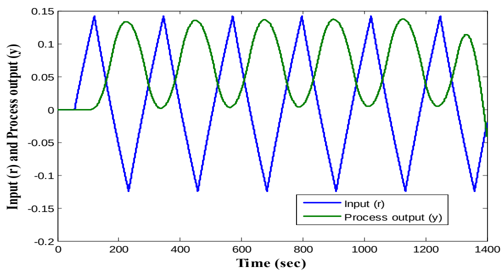

Fig.6. Repetitive Excitation Signal for the NMRCS

Figure 7 shows the reference input r and process output y of NMRCS which are 180 out of phase. After tracking performance is consummate through the repetitive control strategies, the signals W and U are attained. By using the recursive least squares algorithm, the signals W and U are exercised to find the optimum PI controller parameters and are reported in Table 2.

Table 2. PI Controller Parameters

Control loop	K_c	K_I
ZN PI	-5.6	-0.031
NMRCS	-5.49	-0.01

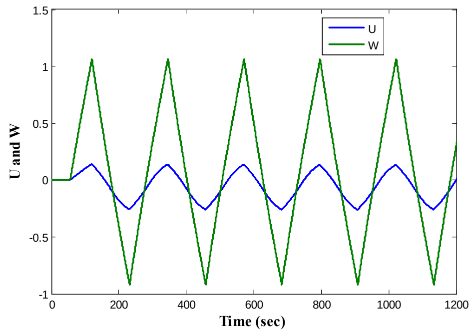

Fig.7. Reference input r and process output y of NMRCS

Simulation run of Tea plant is carried out with NMRCS based PI values. Initially the tea plant is maintained at 40 % of dryer temperature. After that, a step size of 10% of change in temperature is applied to control loop and output is recorded in the Figure 8. Similar test runs of ZN based PI is carried out and the response is traced in the same figure.(Figure 8). From the results, the performances of each control scheme are analyzed in terms of ISE and IAE and the performance indices are tabulated in Table 3. To examine the adaptability of NMRC controller, another operating points of 50% and 60% of dryer temperature are executed. The corresponding responses are traced in figures 9 and 10 and their performance indices are tabulated in same Table. From the results, it is noted that NMRCS based PI mode gives finer performance than the ZN based PI mode.

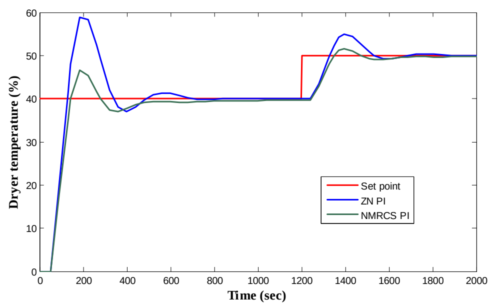

Fig.8. Servo responses of NMRCS and ZNPI at 40% OP

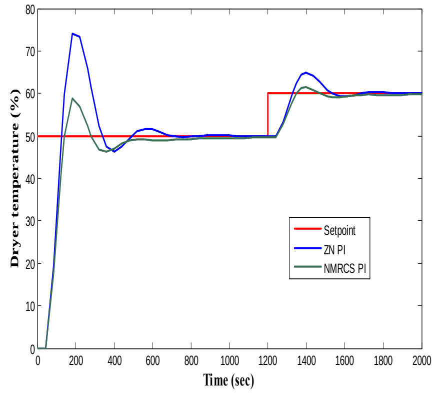

Fig.9. Servo responses of NMRCS and ZNPI at

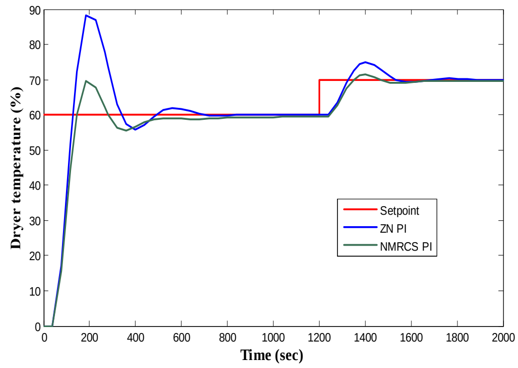

Fig.10. Servo responses of NMRCS and ZNPI at 60% OP50% OP

Table 3. Performances indices for ZN PI and NMRCS PI

Sl.no	Operating Region (%)	ZN PI		NMRCS PI	
		ISE	IAE	ISE	IAE
1	40	10380	1650	9074	1347
2	50	10363	1639	9216	1366
3	60	10360	1635	9362	1386

To test the robustness of the proposed controller, an abrupt disturbance is forcibly given to the control loop at 2000 sec in the 40%,50% and 60% of the operating temperatures and the responses are recorded from Figures 11to13. From the responses, it is sighted that the proposed PI controller furnishes better performance in all cases.

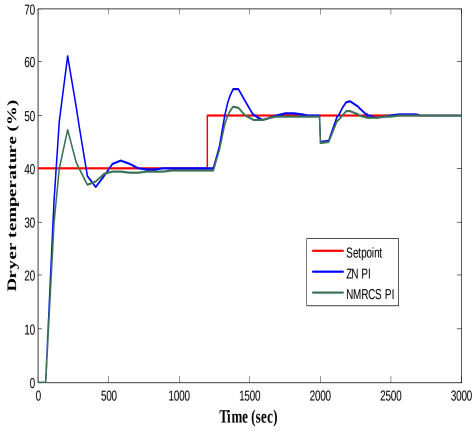

Fig.11. Servo Regulatory responses of NMRCS and ZNPI at 40% OP

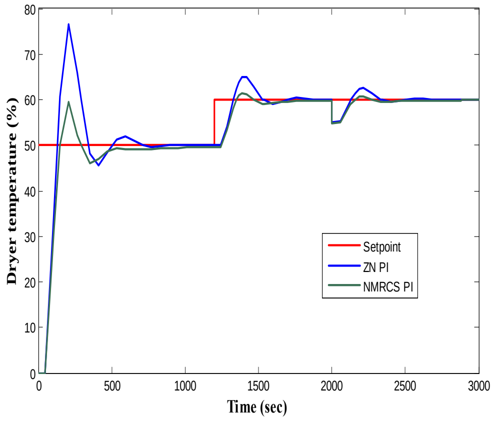

Fig.12. Servo Regulatory responses of NMRCS and ZNPI at 50% OP

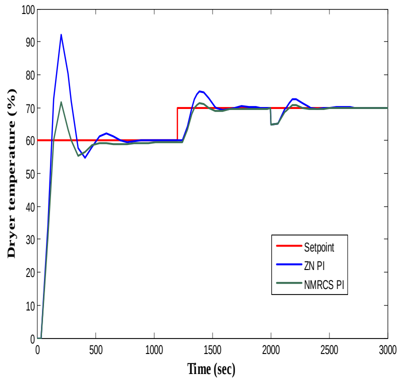

Fig.13. Servo Regulatory responses of NMRCS and ZNPI at 60% OP

Real time implementation

Real time runs of Tea plant is carried out with NMRCS and ZN based PI values at the operating range of 40 % of dryer temperature. A step size of 5% of change in dryer temperature is applied to control loop and output is recorded in the Figure 14 and Figure 15. From the responses the performance measures are calculated and tabulated in Table 4.

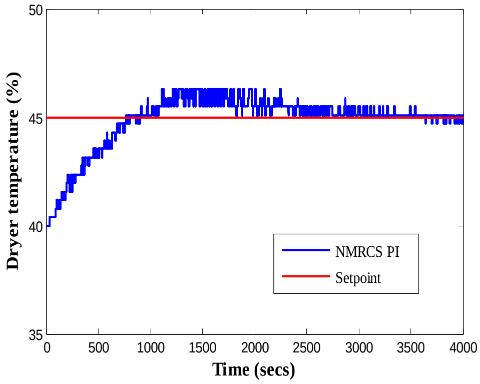

Fig.14. Real time responses of NMRCS PI controller

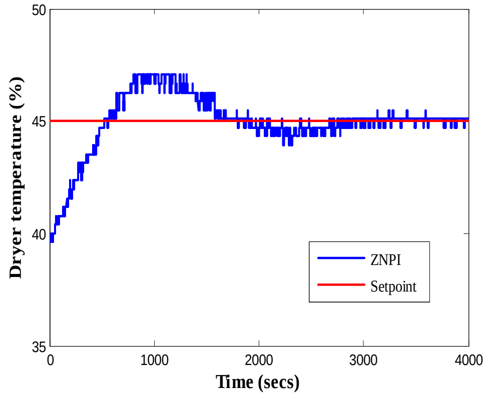

Fig.15. Real time responses of ZN PI controller

Table 4. Performances indices for ZN PI and NMRCS PI in Real time

Sl.no	Operating Region (%)	ZN PI		NMRCS PI	
		ISE	IAE	ISE	IAE
1	40	7298	2245	5624	1436

Results prove that significant difference in the error by adapting the proposed tuning strategy in the tea plant. After improvements, a higher flame temperature is attained under same hot air condition and firewood consumption is reduced as shown in Table 5.

Table 5. Firewood Consumption

Sl.no	Operating Region (%)	Firewood Consumption	
		ZN PI	NMRCS PI
1	40	12 kg	9.6 kg

By reducing fuel consumption, it is thus possible to reduce CO_2 emission to a considerable extent.

VI. CONCLUSION

It is evidently prove that an application of new control strategy in the air heating stove which leads to reduction in many parameters such as wood feeding, CO_2, cost of woods etc. Moreover, the controller also takes care of the entire tea plant in an efficient way. Results show that proposed control strategy dominates in the control loop.

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